

Table of Contents

	<u>Page</u>
1. INTRODUCTION	1-1
1.1 Background	1-1
1.2 Project MOHAVE Goals and Objectives	1-3
1.3 Guide to Report	1-3
2. STUDY SETTING	2-1
2.1 The Southwestern United States	2-1
2.1.1 Land Use	2-1
2.2 Meteorology	2-3
2.3 Air Quality and Visibility	2-5
3. MONITORING NETWORK	3-1
3.1 Air Quality Monitoring Network	3-1
3.1.1 Aerosol Measurements	3-1
3.1.2 Filter Sample Analysis	3-8
3.1.3 Gas Phase Measurements	3-8
3.2 Tracer Release Network	3-10
3.3 Tracer Monitoring Network	3-12
3.1.1 Calculation of Ambient PFT Concentrations	3-18
3.4 Optical Monitoring Network	3-20
3.5 Meteorological Monitoring Network	3-20
4. MEASUREMENT EVALUATION	4-1
4.1 Optical Data Quality	4-1
4.1.1 Nephelometers	4-1
4.1.2 Transmissometers	4-2
4.1.3 Light Absorption	4-4
4.2 Aerosol Data Quality	4-5
4.2.1 UCD IMPROVE Samplers	4-5
4.1.2 BYU Aerosol Sampling	4-18
4.1.3 Harvard HEADS Sampler	4-22
4.3 Aerosol Size Distribution Measurements	4-24
4.3.1 ADI Size Distribution Measurements	4-24
4.3.2 UM MOUDI Measurements	4-25
4.3.3 University of Minnesota Particle Growth Measurements	4-27
4.4 Precision of Tracer Measurements	4-27
4.5 Meteorological data quality.	4-31
4.5.1 Upper-Air Wind Speed and Direction	4-31
5. LIGHT EXTINCTION IN THE DESERT SOUTHWEST	5-1
5.1 Principles of Light Extinction	5-1
5.2 Light Extinction in the Southwest	5-2
5.3 Haze Levels at the Grand Canyon	5-3
5.4 Diurnal Variation of Light Extinction and Its Components	5-5

5.4.1	Light Extinction	5-5
5.4.2	Particle Light Scattering	5-9
5.4.3	Particle Light Absorption	5-10
5.4.4	Calculating Total Extinction from Components	5-11
5.5	Spatial Variability of Light Extinction and Its Components.	5-14
6.	CHEMICAL CONTRIBUTIONS TO EXTINCTION	6-1
6.1	Median and Maximum Concentrations of Chemical Components over the Study Region	6-1
6.2	Temporal and Spatial Variation of Contributions to Extinction	6-9
6.3	Frequency of Different Atmospheric Constituents' Contribution to Different Levels of Haze	6-12
7.	TEMPORAL CHANGES IN METEOROLOGY, TRANSPORT, AND AIR QUALITY	7-1
7.1	Representativeness of Meteorology and Air Quality	7-1
7.1.1	Meteorology	7-1
7.1.2	Light Extinction	7-2
7.1.3	Sulfate	7-2
7.2	Transport Patterns	7-5
7.2.1	Seasonal synoptic scale transport patterns	7-5
7.2.2	Effect of transport patterns upon haze levels	7-7
7.2.3	Mesoscale transport patterns	7-9
7.2.4	Influence Functions	7-10
7.3	Effect of Sulfur Dioxide Emissions Reductions on Sulfate Concentrations in the Western U.S. since 1979	7-14
7.3.1	SO ₂ Emissions Trends	7-15
7.3.2	Particulate Sulfur Trends	7-15
8.	SOURCE CONTRIBUTION ASSESSMENT METHODOLOGY	8-1
8.1	Overview of Attribution Approach	8-1
8.2	Evaluation of Initial Attribution Methods	8-2
8.3	Descriptions of Final Attribution Methods	8-5
8.3.1	Tracer Max (Tracer Scaling)	8-10
8.3.2	Exploratory Data Analyses	8-10
8.3.3	Tracer Regression.	8-11
8.3.4	TAGIT	8-11
8.3.5	Modified CMB (MCMB)	8-12
8.3.6	TMBR	8-13
8.3.7	DMBR	8-13
8.3.8	Modified HAZEPUFF	8-14
8.3.9	CALMET/CALPUFF	8-14
8.3.10	HOTMAC/RAPTAD/ROME	8-16
8.3.11	Evaluation of Windfields	8-17
8.4	Computer Simulation of Visual Air Quality	8-18
8.4.1	Radiative Transfer Concepts	8-18
8.4.2	Image Processing Techniques	8-19

8.4.2	Human Perception of Visibility Change	8-19
8.5	Discussion of Assessment Results	8-21
9.	SOURCE CONTRIBUTIONS ASSESSMENT	9-1
9.1	What is the a priori basis for believing that MPP could be an important source of haze at GCNP?	9-1
9.2	What do pre-Project MOHAVE assessments indicate about source contributions to visibility impairment at GCNP?	9-2
9.3	What can we learn about source contributions directly from the Project MOHAVE data?	9-5
9.3.1	Spatial Pattern Analyses	9-5
9.3.2	Modified CMB Attributions	9-6
9.3.3	Perfluorocarbon and Halocarbon Tracer Analyses	9-6
9.4	What is a likely range of 12-hour MPP contributions to GCNP sulfate during the intensive monitoring periods?	9-11
9.5	What is a likely range of 12-hour and 24-hour MPP contributions to GCNP light extinction during the intensive monitoring periods?	9-21
9.6	What can we say about MPP impacts on haze at GCNP during periods without tracer data?	9-33
9.7	What can we infer about short-term (e.g., 3-hour) impacts on haze at GCNP?	9-35
9.8	How noticeable are the changes in haze that correspond to various fractional changes in light extinction?	9-36
9.9	Level of confidence in the Project MOHAVE Findings	9-37
10.	SUMMARY AND CONCLUSIONS	10-1
10.1	Evaluate the measurements for applicability to modeling and data analysis activities.	10-1
10.2	Describe the visibility, air quality and meteorology during the field study period and determine the degree to which these measurements represent typical visibility events at the Grand Canyon.	10-1
10.3	Further develop conceptual models of physical and chemical processes which affect visibility impairment at the Grand Canyon.	10-3
10.4	Estimate the contributions from different emissions sources to visibility impairment at the Grand Canyon, and quantitatively evaluate the uncertainties of those estimates.	10-3
10.5	Reconcile different scientific interpretations of the same data and present this reconciliation to policy-makers.	10-3
10.6	Technical Lessons Learned as a Result of Project MOHAVE	10-4

11. REFERENCES	11-1
-----------------------	-------------

APPENDICES

A. DATA BASE CONTENTS AND STRUCTURE	A-1
B. APPROACH FOR ESTIMATING SHORT-TERM IMPACTS OF MPP AT MEADVIEW	B-1
C. DESCRIPTIONS OF ATTRIBUTION METHODS AND THEIR APPLICATION	C-1

List of Figures

		<u>Page</u>
Figure A	Project MOHAVE Site Map	ii
Figure 2-1	Geographic features of the Southwestern U.S.	2-2
Figure 2-2	Major cities and roadways in the southwestern United States.	2-3
Figure 2-4	Class I areas in California, Nevada, Utah, and Arizona.	2-4
Figure 2-5	Radar wind profiler summary for the summer intensive period at Mohave Power Plant.	2-6
Figure 2-6	Rawinsonde summary for the summer intensive period at Cottonwood Cove.	2-6
Figure 3-1	Air quality monitoring network for measurements of aerosol composition and gaseous species.	3-9
Figure 3-2	Tracer release and monitoring network.	3-13
Figure 3-3	Time series of oPDCH tracer release rate, power load, and SO ₂ emission at MPP during the winter intensive.	3-14
Figure 3-4	Time series of oPDCH tracer release rate and power production at MPP during the summer intensive.	3-15
Figure 3-5	Time series of hourly average PMCP tracer release rate from Dangling Rope during the winter intensive.	3-16
Figure 3-6	Time series of hourly average PMCP tracer release rate from Tehachapi Summit during the summer intensive.	3-16
Figure 3-7	Time series of hourly average PMCH tracer release rate from Tehachapi Summit during the summer intensive.	3-17
Figure 3-8	Time series of hourly average PTCH tracer release rate from El Centro during the summer intensive.	3-17
Figure 3-9	Optical properties network from Project MOHAVE including total extinction coefficient and particle scattering coefficient.	3-21
Figure 3-10	Meteorological observation sites.	3-23
Figure 4-1	Comparison of sulfur collected on Teflon A and measured by PIXE with sulfate collected on nylon B and measured by ion chromatography.	4-14
Figure 4-2	Comparison of two organic measurements, OMC and OMH, collected at the nine IMPROVE sites.	4-15
Figure 4-3	Map of ratio of mean ammonium sulfate to mean organic by hydrogen for the summer intensive based on data from the IMPROVE samplers.	4-16
Figure 4-4	Comparison of gravimetric mass (MF) and calculated mass (CALMA) at all Project MOHAVE IMPROVE sites.	4-17

Figure 4-5	Comparison of gravimetric mass (MF) and calculated mass (RCMC) at all Project MOHAVE IMPROVE sites.	4-17
Figure 4-6	Comparison of XRF and PIXE for all Project MOHAVE IMPROVE summer samples for iron and zinc.	4-18
Figure 4-7	Regression of collocated PMCP tracer measurements at Meadview during the winter intensive period.	4-28
Figure 4-8	Regression of collocated ocPDCH measurements at Meadview during the winter intensive period.	4-28
Figure 4-9	Scatter plots of collocated tracer measurements at Meadview, summer intensive period.	4-29
Figure 4-10	Time series of collocated BNL and DOE-EML tracer measurements at Dolan Springs, summer intensive period.	4-31
Figure 4-11	Comparison of direction measured by the MPP radar wind profiler and Bullhead City-Riviera rawinsonde during the second half of January 1992.	4-33
Figure 4-12	Comparison of wind speed measured by the MPP radar wind profiler and Bullhead City-Riviera rawinsonde during the second half of January 1992.	4-33
Figure 5-1	Map showing mean annual levels of b_{ext} (in Mm^{-1}) at Class I areas throughout the United States.	5-2
Figure 5-2	Comparison of 12-hour averaged b_{ext} measured in (GRCW) and on the rim of (GRCA) the Grand Canyon.	5-4
Figure 5-3	Comparison of 12-hour averaged b_{ext} measured at Meadview (MEAD) and within the Grand Canyon (GRCW).	5-4
Figure 5-4	Time series of wintertime hourly light extinction at MEAD, GRCA, and GRCW.	5-6
Figure 5-5	Time series of summertime hourly light extinction at MEAD, GRCA, and GRCW.	5-7
Figure 5-6	Diurnal variation of light extinction on the west side of the Grand Canyon at Meadview (Meadview), within the Grand Canyon (GRCW), and on the south rim of the Grand Canyon (GRCA).	5-8
Figure 5-7	Diurnal variation of light scattering by particles measured at Meadview AZ.	5-9
Figure 5-8	Time series of particle light scattering (b_{sp}) at MEAD.	5-10
Figure 5-9	Time series of measured b_{abs} from 12 hour duration filters.	5-11
Figure 5-10	Extinction balance comparison of the sum of b_{abs} , b_{sg} , b_{sp} , and CMS/2 with total b_{ext} at MEAD during the summer intensive study.	5-12
Figure 5-11	Comparison of measured extinction with calculated extinction ($b_{\text{sg}} + b_{\text{sp}} + \text{CMS}/2 + b_{\text{ap}}$).	5-13

Figure 5-12	Comparison of two measurements of light extinction. The line is the 1:1 line.	5-14
Figure 5-13	Map of summertime calculated light extinction.	5-15
Figure 6-1	Wintertime average PM _{2.5} composition at sampling sites within the Project MOHAVE study area.	6-8
Figure 6-2	Summertime average PM _{2.5} composition at sampling sites within the Project MOHAVE study area.	6-8
Figure 6-3	Wintertime average spatial distribution of chemical components.	6-10
Figure 6-4	Summertime average spatial distribution of chemical components.	6-10
Figure 6-5	Seasonally averaged relative light extinction components from Meadview.	6-11
Figure 6-6	Wintertime relative (left panel) and absolute (right panel) calculated extinction at Meadview.	6-13
Figure 6-7	Summertime relative (left panel) and absolute (right panel) calculated extinction at Meadview.	6-14
Figure 6-8	Winter relative chemical contribution frequency distribution to light extinction at Meadview based on IMPROVE data.	6-15
Figure 6-9	Summer relative chemical contribution frequency distribution to light extinction at Meadview based on IMPROVE data.	6-16
Figure 7-1	Frequency distribution of light extinction at Grand Canyon by season and year: south rim, summer (May – October).	7-3
Figure 7-2	Frequency distribution of light extinction at Grand Canyon by season and year: south rim, winter (November – April).	7-3
Figure 7-3	Frequency distribution of light extinction at Grand Canyon by season and year: in-canyon, summer (May – October).	7-4
Figure 7-4	Frequency distribution of light extinction at Grand Canyon by season and year: in-canyon, winter (November – April).	7-4
Figure 7-5	Frequency distribution of particulate sulfur at Meadview for the MOHAVE summer intensive period (July 13 – September 2) compared to the same period for SCENES.	7-6
Figure 7-6	Frequency distribution of particulate sulfur at Hopi Point for the MOHAVE summer intensive period (July 13 – September 2) compared to the same period for SCENES (1984-1989) and IMPROVE (1987-1997).	7-6
Figure 7-7	Percent of trajectories passing over 2 degree longitude by 2 degree latitude grid cells en route to Grand Canyon.	7-8
Figure 7-8	Probability that air arrived at Grand Canyon with low light extinction (lowest 20 th percentile) after passing over each area.	7-9

Figure 7-9	Maps of the frequency that tracer was detected above background for each of the four PFT release locations.	7-11
Figure 7-10	Map of average PFT influence functions (10^{-9} s/m ³) measured at receptor sites.	7-12
Figure 7-11	Trends in SO ₂ emissions in 5 southwestern states.	7-14
Figure 7-12	Annual average particulate sulfur concentrations measured by the WFPN and IMPROVE at Hopi Point in Grand Canyon National Park and at three other nearby locations.	7-16
Figure 7-13	Annual average particulate sulfur concentrations measured by the WFPN and IMPROVE at three locations away from the Colorado Plateau.	7-18
Figure 8-1	Change in apparent target contrast for % change in ambient extinction.	8-22
Figure 8-2	Source attribution sulfate time series from receptor models for MPP at Meadview during the summer intensive.	8-23
Figure 8-3	Source attribution sulfate time series from simulation models for MPP at Meadview during the summer intensive.	8-23
Figure 8-4	Source attribution sulfate time series from all models for MPP at Meadview during the summer intensive. Measured sulfate and tracer potential are also included for comparison.	8-23
Figure 8-5	Source attribution sulfate time series for MPP at Hopi Point during the summer intensive.	8-24
Figure 8-6	Source attribution sulfate time series for MPP at Meadview during the winter intensive.	8-24
Figure 8-7	Source attribution sulfate time series for MPP at Hopi Point during the winter intensive.	8-24
Figure 9-1	Scatter plot of light scattering and MPP tracer at Meadview - 12 hour averaging time.	9-8
Figure 9-2	Scatter plot of light scattering and MPP tracer at Meadview - 1 hour averaging time.	9-8
Figure 9-3	Time series of measured light extinction and modeled light extinction as a linear function of methylchloroform and water vapor concentration.	9-9
Figure 9-4	20 th , 50 th , and 80 th percentile ocPDCH tracer concentration at Meadview by hour of day, July 28- August 14, 1992.	9-11
Figure 9-5	Cumulative frequency plots of 12 hour sulfate attribution to MPP at Meadview during the summer intensive.	9-13
Figure 9-6	Cumulative frequency plots of 12 hour sulfate attribution to MPP at Hopi Point during the summer intensive.	9-14
Figure 9-7	Cumulative frequency plots of 12 hour sulfate attribution to MPP at Meadview during the winter intensive.	9-15

Figure 9-8	Cumulative frequency distributions of 12-hour estimated MPP percentage contributions to particulate sulfate concentration at Meadview during the summer intensive.	9-18
Figure 9-9	Cumulative frequency distributions of 12-hour estimated MPP percentage contributions to particulate sulfate concentration at Hopi Point during the summer intensive.	9-19
Figure 9-10	Cumulative frequency distributions of 12-hour estimated MPP percentage contributions to particulate sulfate concentration at Meadview during the winter intensive.	9-20
Figure 9-11	Cumulative frequency distributions of 12-hour estimated MPP percentage contributions to measured light extinction at Meadview during the summer intensive.	9-22
Figure 9-12	Cumulative frequency distributions of 12-hour estimated MPP percentage contributions to measured light extinction at Hopi Point during the summer intensive.	9-23
Figure 9-13	Cumulative frequency distributions of 12-hour estimated MPP percentage contributions to measured light extinction at Meadview during the winter intensive.	9-24
Figure 9-14	Cumulative frequency distributions of 12-hour estimated MPP percentage contributions to calculated light extinction at Meadview during the summer intensive.	9-27
Figure 9-15	Cumulative frequency distributions of 12-hour estimated MPP percentage contributions to calculated light extinction at Hopi Point during the summer intensive.	9-28
Figure 9-16	Cumulative frequency distributions of 12-hour estimated MPP percentage contributions to calculated light extinction at Meadview during the winter intensive.	9-29
Figure 9-17	Cumulative frequency distributions of 24-hour estimated MPP percentage contributions to measured light extinction at Meadview during the summer intensive.	9-30
Figure 9-18	Cumulative frequency distributions of 24-hour estimated MPP percentage contributions to measured light extinction at Hopi Point during the summer intensive.	9-31
Figure 9-19	Cumulative frequency distributions of 24-hour estimated MPP percentage contributions to measured light extinction at Meadview during the winter intensive.	9-32
Figure 9-20	Frequency distribution of CALPUFF Dry predicted MPP particulate sulfate at Meadview by 2 month period, 1992.	9-34
Figure 9-21	Frequency distribution of predicted percent MPP-caused light extinction at Meadview using CALPUFF Dry, by 2 month period, 1992.	9-34

Figure 9-22:	Time plots of the particulate sulfate yield for each 12-hour period that would be required to generate 1% and 10% of the measured light extinction coefficient in summer at Meadview.	9-40
Figure 9-23	Time plots of the particulate sulfate yield for each 12-hour period that would be required to generate 1% and 10% of the measured light extinction coefficient in summer at Hopi Point.	9-40
Figure 10-1	Cumulative frequency distributions of predicted and measured ocPDCH concentrations at Meadview for the summer intensive study period.	10-6
Figure 10-2	Cumulative frequency distributions of predicted and measured ocPDCH concentrations at Hopi Point for the summer intensive study period.	10-6
Figure B-1:	Estimate time scales for tracer impact of Meadview on various dates.	B-1
Figure B-2:	Adjustment factor for converting 24 hour MPP estimated contribution to light extinction coefficient to short term impact.	B-3
Figure B-3:	Daily average ocPDCH tracer concentration at Meadview versus duration of tracer impact.	B-4
Figure B-4:	Estimates of MPP attributed sulfate versus duration of tracer impact.	B-4
Figure B-5:	One hour time series of observed ocPDCH concentration and CALPUFF predicted tracer concentrations.	B-5
Figure B-6:	Ratios of maximum 3 hour CALPUFF predicted tracer concentration to 12 and 24 hour average values.	B-7

List of Tables

	<u>Page</u>
Table A	iv
Table B	viii
Table C	viii
Table D	viii
Table E	viii
Table F:	ix
Table G	ix
Table H	ix
Table 2-1	2-7
Table 2-2	2-8
Table 3-1	3-2
Table 3-2	3-6
Table 3-3	3-7
Table 3-4	3-7
Table 3-5	3-7
Table 3-6	3-8
Table 3-7	3-18
Table 3-8	3-20

Table 3-9	Locations and purposes of supplemental upper-air meteorological monitoring for Project MOHAVE.	3-22
Table 4-1	Mean relative precisions for variables measured by PIXE, PESA, XRF, and LIPM on the Teflon A filter.	4-8
Table 4-2	Mean relative precisions for mass, carbon, ion, and SO ₂	4-8
Table 4-3	BYU Completeness of sample collection and analysis during project MOHAVE winter and summer intensive studies.	4-19
Table 4-4	Summary of BYU Aerosol Measurement Precision	4-20
Table 4-5	Precisions and Average Measured Concentrations from Harvard HEADS Measurements	4-23
Table 4-6	Estimates of Lower Quantifiable Limits of Harvard HEADS Measurements	4-24
Table 4-7	Precisions and Lower Quantifiable Limits for MOUDI Ion and Carbon Measurements	4-26
Table 4-8	Root-mean-square error (fL/L) for collocated sites.	4-29
Table 4-9	Standard deviation (fL/L) of pre-release and interim PFT concentrations.	4-30
Table 4-10	RMS error and r^2 for DOE-EML collocated tracer measurements at Dolan Springs.	4-30
Table 4-11	Comparison of winds from rawinsonde and radar wind profiler.	4-34
Table 5-1	Summary of 12 hour average Transmissometer Measurements near Grand Canyon National Park.	5-3
Table 6-1	Median aerosol concentrations from the Project MOHAVE wintertime intensive sampling period (1/14/92 – 2/15/92).	6-2
Table 6-2	Maximum aerosol concentrations from the Project MOHAVE wintertime intensive sampling period (1/14/92 – 2/15/92).	6-3
Table 6-3	Median aerosol concentrations from the Project MOHAVE summertime intensive sampling period (7/12/92 – 9/2/92).	6-4
Table 6-4	Maximum aerosol concentrations from the Project MOHAVE summertime intensive sampling period (7/12/92 – 9/2/92).	6-5
Table 6-5	Row heading definitions for Tables 6-1 through 6-4.	6-6
Table 7-1.	Chronology of Class I Area Particulate Matter Measurements	7-15
Table 8-1	Summary of Evaluations of Initial Attribution Methods against PFT Measurements	8-4
Table 8-2	Methods Used to Estimate Source Contributions	8-6
Table 8-3	Principal Assumptions of the Apportionment Methods	8-8
Table 9-1	Range of estimated 12-hour MPP sulfate (ng/m ³) for the 50th and 90th percentile conditions.	9-16

Table 9-2	Cross-correlation coefficients (r) for predicted MPP sulfate by the various methods and the tracer concentrations, measured sulfate and transmissometer extinction coefficients for summer at Meadview.	9-17
Table 9-3	Range of estimated 12-hour MPP fraction of measured sulfate (%) for the 50th and 90th percentile conditions.	9-17
Table 9-4	Range of estimated 12-hour MPP fraction (%) of measured light extinction coefficient for the 50th and 90th percentile conditions.	9-21
Table 9-5	Range of estimated 12-hour MPP fraction (%) of calculated light extinction coefficient for the 50th and 90th percentile conditions.	9-25
Table 9-6	Range of estimated 24-hour MPP fraction (%) of measured light extinction coefficient for the 50th and 90th percentile conditions.	9-25
Table 9-7	Ratio of CALPUFF Dry estimated MPP 12-hour sulfate values for 50th and 90th percentile conditions for months not during the intensive monitoring period to corresponding values estimated for July and August.	9-35
Table 9-8	Ratio of CALPUFF Dry estimated 12-hour MPP fraction of the light extinction coefficient values for 50th and 90th percentile conditions for months not during the intensive monitoring period to corresponding values estimated for July and August.	9-35
Table A-1	Abbreviation for contractors.	A-2
Table A-2	dBASE IV site documentation files.	A-5